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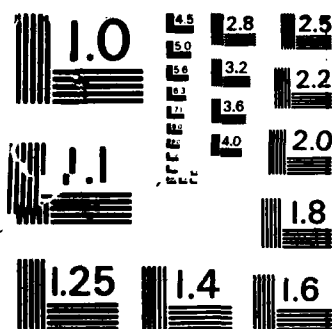
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Final Scientific Report

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HIGH-LATITUDE IONOSPHERIC IRREGULARITIES

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| 19. ABSTRACT (Continue on reverse if necessary and identify by block number) We provide a brief summary of some of the key results contained in the twenty-seven journal articles produced under support from this contract. These results all involve the production, transport, and ultimate decay of naturally occurring ionospheric plasma structure. | | | | |
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I SUMMARY OF KEY RESULTS

The study of ionospheric plasma structure and high-latitude dynamics is a rapidly evolving field. The progress being made is, in large part, a result of the conscious interaction between theory, experiment, and innovative data analysis techniques. Under support from the Air Force Office of Scientific Research, we have conducted a three-year investigation into naturally occurring ionospheric plasma structure. During the course of the contract, twenty-seven* journal articles have been produced that represent a blend between theory and experiment. Herein, we briefly highlight some of the key scientific results contained in those articles.

Structure in ionospheric plasma concentration is commonplace at high latitudes, ranging in scale size (perpendicular to the geomagnetic field) from hundreds of kilometers to centimeters. This enormous range of scale sizes necessitates the use of diverse complementary diagnostics for its study. In our work, we have made use of remote measurements from incoherent-scatter and radio-wave scintillation, and in situ satellite and rocket observations. These experimental data are interpreted in the framework of theory and modeling developed concurrently.

The amplitude of ionospheric irregularities observed at a point is a strong function of local electrodynamics, as well as the history of the magnetic-flux tube to which the plasma is tied. The experimentally observed plasma-fluctuation spectrum constitutes a balance between the strengths and scale-size dependencies of structure production and dissipation processes--none of which are well understood. Despite the large variety of physical mechanisms contributing to the irregularity spectrum ultimately observed, we have found that our framework proposed earlier

* These references are contained (in chronological order) in the cumulative publication list in Section II.

for structure morphology is still applicable [Vickrey and Kelley, 1983].[†] That framework consists of accurately specifying (1) the source of plasma structure, (2) the lifetime of structure once produced, and (3) the convection pattern to which the structure is subjected during its lifetime.

The subject of most of our journal articles falls into one of these three categories. For example, Kelly and Vickrey [1984] showed that on the dayside, important sources of high-latitude F-layer plasma are directly tied to the convection pattern. Enhanced electron densities and soft auroral arcs are consistently seen in Sondrestrom radar data at the afternoon-sector convection-reversal boundary, where the magnetospheric electric field converges. They also point out that solar-produced plasma convected from lower latitudes is an important source of polar-cap ionization. This suggests seasonal variations in polar-cap morphology, that have been borne out in the HILAT observations [Livingston et al., 1986a].

Robinson et al. [1985] examined the precipitation-source function in the nighttime auroral oval. They showed that a precipitation-source function coincident with the upward field-aligned current pattern at the Harang discontinuity is required to reproduce Chatanika radar observations. This modeling effort also showed that plasma structuring and steepening is a natural consequence of incompressible convective flow—even in a well-behaved potential pattern.

The possibility of producing structure in plasma density by a structured convection-velocity field has been recognized for some time, e.g., Vickrey and Kelley [1983]. It has now been demonstrated experimentally at large scales in the work of Tsunoda et al. [1986] using the EISCAT radar, and by Vickrey et al. [1986] using in situ data from the HILAT satellite.

[†]Vickrey, J. F., and M. C. Kelley, "Irregularities and Instabilities in the Auroral F Region," High-Latitude Space Plasma Physics, 95-113, Plenum Press, 1983.

Any credible, physical model of solar-wind magnetosphere-ionosphere interaction must accurately represent the interchange of energy at various various scale-size regimes. This implies that the current-voltage relationships of the magnetosphere-ionosphere circuit are accounted for properly. Robinson [1984] examined statistical radar observations that, for global-scale sizes, implied that the cross-polar cap potential and the total dissipative ionospheric current are linearly related. At smaller scale sizes (tens of kilometers), Vickrey et al. [1986] have shown, using HILAT observations, that the magnetosphere behaves as a constant current source. The measured magnetic fluctuation levels (that are proportional to field-aligned currents) are nearly independent of season, and hence, of ionospheric conductivity. This fundamental property of the magnetosphere has dramatic implications for the production of velocity and, ultimately, density structure. For example, to preserve divergence-free current flow everywhere, we might expect the velocity-field structure to be enhanced in the lower conducting winter hemisphere. This tendency is very striking in the observations presented by Vickrey et al. [1986].

In recent investigations into the spectral characteristics of magnetospheric electrodynamics and Poynting flux, Vickrey et al. [1986] found that power-law slopes of magnetometer fluctuations are often shallow. When these slopes are more shallow than k^{-1} , (where k is the wavenumber), it implies that the spectra of field-aligned currents producing the perturbations have a positive power-law slope. Of course, this slope must eventually roll over at some scale size, suggesting a favored scale size for field-aligned currents. This unexpected spectral behavior, combined with observations of significant upward Poynting flux, led us to suspect hydromagnetic waves as the source for at least some of our magnetometer fluctuations. Vickrey et al. [1986] went on to show that by combining electric-field and magnetometer measurements, waves can be distinguished from steady-state current systems. Their observations indicate the occurrence of both at high latitudes. Similar evidence for hydromagnetic waves is presented by Tsunoda et al. [1986], who measured their polarization characteristics using the EISCAT radar. This distinc-

tion between hydromagnetic waves and steady-state processes is important for irregularity studies because steady-state current and electric-field structure produces electron-density structure, while waves do not.

As mentioned above, we view the observed spectrum of structure as reflecting a balance between source and dissipative mechanisms. The papers by Vickrey et al. [1984], Livingston et al. [1984], and Heelis et al. [1985] describe our experimental and theoretical attempts to examine the diffusion processes that ultimately remove F-region plasma structure. The experimental evidence indicates that the effective rate of diffusion of plasma across magnetic-field lines in the F layer depends on the scale size of the structure being removed. Although this result sounds surprising at first, we have shown theoretically that diffusion rates depending on scale size are a natural consequence of the electrical coupling along magnetic-field lines between the E and F layers. We have developed a model that predicts the temporal evolution of an arbitrary initial spectrum of F-region structure. Although each scale size is assumed to evolve independently (i.e., nonlinear mode coupling is not included), all important E-region coupling effects (including image irregularity formation) are retained. This model has shown that E-region processes can dominate the evolution of the F-layer spectrum. The model is currently being refined and expanded to allow examination of the altitude dependence of current closure, image formation, and related effects. In a parallel effort, the question of nonlinear mode coupling is being addressed. It is hoped that these separate modeling efforts can eventually be merged.

This brief summary has only highlighted a few of the significant new results that have been supported by this contract. The volume of journal publications reflects the rapid pace at which progress in understanding plasma structuring processes is being made. We hope, under future AFOSR support, to continue this progress.

II CUMULATIVE LIST OF JOURNAL PUBLICATIONS PRODUCED
UNDER SUPPORT FROM THIS CONTRACT

A. Journal Publications

- Rino, C. L., R. C. Livingston, R. T. Tsunoda, R. M. Robinson, J. F. Vickrey, C. Senior, M. D. Cousins, J. Owen, and J. A. Klobuchar, "Recent Studies of the Structure and Morphology of Auroral Zone F-Region Irregularities," Radio Sci., 18(6), 1167-1180, 1983.
- Kamide, Y., R. M. Robinson, S.-I. Akasofu, and T. A. Potemra, "Auroral and Electrojet Configuration in the Early-Morning Sector," J. Geophys. Res., 89(A1), 389-393, 1984.
- Robinson, R. M., "K_p Dependence of Auroral Zone Field-Aligned Current Intensity," J. Geophys. Res., 89(A3), 1743-1748, 1984.
- Vickrey, J. F., M. C. Kelley, R. Pfaff, and S. R. Goldman, "Low-Altitude Image Striations Associated with Bottomside Equatorial Spread F-- Observations and Theory," J. Geophys. Res., 89(A5), 2955-2961, 1984.
- Robinson, R. M., and R. R. Vondrak, "Measurements of E-Region Ionization and Conductivity Produced by Solar Illumination at High Latitudes," J. Geophys. Res., 89(A6), 3951-3956, 1984.
- Robinson, R. M., T. A. Potemra, D. S. Evans, and J. D. Kelly, "Radar and Satellite Measurements of an F-Region Ionization Enhancement in the Post-Noon Sector," Geophys. Res. Letts., 11(9), 899-902, 1984.
- Kelly, J. D., and J. F. Vickrey, "F-Region Ionospheric Structure Associated with Antisunward Flow Near the Dayside Polar Cusp," Geophys. Res. Letts., 11(9), 907-910, 1984.
- Heelis, R. A., J. F. Vickrey, and N. B. Walker, "Electrical Coupling Effects on the Temporal Evolution of F-Layer Plasma Structure," J. Geophys. Res., 90(A1), 437-445, 1985.
- Tsunoda, R. T., "Control of the Seasonal and Longitudinal Occurrence of Equatorial Scintillation by the Longitude Gradient in Integrated E-Region Pedersen Conductivity," J. Geophys. Res., 90(A1), 447-456, 1985.

- Robinson, R. M., S. B. Mende, R. R. Vondrak, J. U. Kozyra, and A. F. Nagy, "Radar and Photometric Measurements of an Intense Type A Red Aurora," J. Geophys. Res., 90(A1), 457-466, 1985.
- Weber, E. J., R. T. Tsunoda, J. Buchau, R. E. Sheehan, D. J. Strickland, W. Whiting, and J. G. Moore, "Coordinated Measurements of Auroral-Zone Plasma Enhancements," J. Geophys. Res., 90(A7), 6497-6513, 1985.
- Yasuhara, F., Y. Kamide, and J. F. Vickrey, "On the Efficiency of the Cowling Mechanism in the Auroral Electrojet," Geophys. Res. Letts., 12(6), 389-392, 1985.
- Robinson, R. M., R. T. Tsunoda, J. F. Vickrey, and L. Guerin, "Sources of F-Region Ionization Enhancements in the Nighttime Auroral Zone," J. Geophys. Res., 90(A8), 7533-7546, 1985.
- Robinson, R. M., R. R. Vondrak, and T. A. Potemra, "Auroral-Zone Conductivities Within the Field-Aligned Current Sheets," J. Geophys. Res., 90(A10), 9688-9696, 1985.
- Tsunoda, R. T., I. Haggstrom, A. Pellinen-Wannberg, A. Steen, and G. Wannberg, "Direct Evidence of Plasma Density Structuring in the Auroral F-Region Ionosphere," Radio Sci., 20, 762, 1985.
- Vickrey, J. F., R. C. Livingston, M. B. Walker, T. A. Potemra, R. A. Heelis, and F. J. Rich, "On the Current-Voltage Relationship of the Magnetospheric Generator at Small Spatial Scales," Geophys. Res. Letts., 13(6), 495-498, 1986.
- Livingston, R. C., J. F. Vickrey, M. C. Kelley, E. J. Weber, and J. Buchau, "Irregularity Decay in an Isolated Plasma Bubble," submitted for publication, J. Geophys. Res., 1985.
- Tsunoda, R. T., R. C. Livingston, J. F. Vickrey, and C. L. Rino, "Dayside Observations of Thermal-Ion Upwellings at 800-km Altitude: An Ionospheric Signature of the Cleft Ion Fountain," submitted for publication, J. Geophys. Res., 1986.
- Mikkelsen, I.-S., M. F. Larsen, M. C. Kelley, J. F. Vickrey, E. Friis-Christensen, and J. Meriwether, "Simultaneous Measurements of the Thermospheric Wind Profile at Three Separate Positions in the Dusk Auroral Oval," submitted for publication, J. Geophys. Res., 1986.
- Tsunoda, R. T., I. Haggstrom, A. Pellinen-Wannberg, A. Steen, G. Wannberg, and J. F. Vickrey, "EISCAT Observations of Large, Fluctuating Electric Fields During a Pc4 Pulsation Event in the Midnight Sector," submitted for publication, J. Atmos. Terr. Phys., 1986.

B. Manuscripts in Preparation

Vickrey, J. F., R. C. Livingston, N. B. Walker, T. A. Potemra, R. A. Heelis, and F. J. Rich, "The Scale-Size Dependence of Magnetospheric Electrodynamics," to be submitted, Geophys. Res. Letts., 1986.

Livingston, R. C., N. B. Walker, J. F. Vickrey, and M. A. McCready, "High-Latitude Total Electron Content: Solar, Seasonal, and Local-Time Dependence," to be submitted, J. Geophys. Res., 1986a.

Rino, C. L., T. M. Dabbs, and R. C. Livingston, "Equatorial and Auroral-Zone Phase Structure," to be submitted, J. Geophys. Res., 1986.

Rino, C. L., S. T. Zalesak, T. M. Dabbs, "The k Spectrum of Convectively Unstable Plasmas," to be submitted, J. Geophys. Res., 1986.

Livingston, R. C., T. M. Dabbs, and C. L. Rino, "Estimation of Diffraction Effects in Phase Scintillation Measurements," to be submitted, J. Geophys. Res., 1986b.

Livingston, R. C. and E. Weber, "The Spatial Extent of Heater-Induced Irregularities at Arecibo," to be submitted, J. Geophys. Res., 1986c.

Livingston, R. C., R. A. Power, W. B. Hanson, N. B. Walker, and T. M. Dabbs, "Systematic Study of Equatorial In Situ Ionospheric Irregularities," to be submitted, J. Geophys. Res., 1986d.

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